Multi-Spectral Scene Generation Workshop

Redstone Technical Test Center

PSTL:

A Distributed Real-Time Architecture for Physics-based Simulation and Hyper-Spectral Scene Generation

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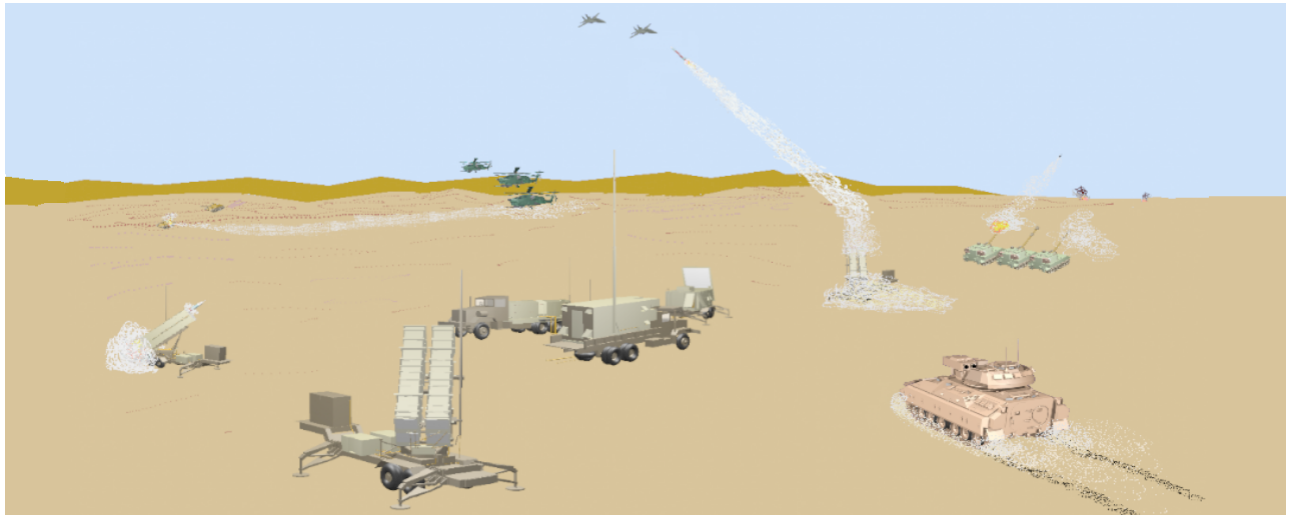
Why We Model

- We are predicting or matching physical phenomena:
  - +Damage statistics of live-fire tests.
  - +Energy levels received by a sensor.
- Hollywood storytellers communicate *feelings* to *people*. "Skin-deep" models are fine for them.



Current & Future Challenges for T&E

- In simulation, re-creating the real-world:
  - +Re-creating individual engineering tests.
    - S&E community starts here.
  - +Re-creating real proving grounds.
  - +Re-creating training centers and training exercises.
  - +Re-creating combat locations and scenarios.
    - Training community & wargamers start here.

The Simulation Challenge

Meeting the Simulation Challenge

- Engineering-level geometric detail.
- Physics-based simulation.
- Realistic 3-D atmosphere, ground, and sea models.
- Fast: Real-time, near-real-time, Web, and offline.

  +Hardware-in-the-loop, man-in-the-loop.
- Common geometry.
- Common software.
- Massively parallel processing.

What is PST?

- PST = PTN and SWISS, Together!
  - +PTN = Paint-the-Night
    - Real-time polygon rendering
    - From CECOM NVESD
  - +SWISS = Synthetic Wide-band Imaging Spectra-photometer and Environmental Simulation
    - Ray-traced BRL-CAD™ CSG geometry
    - From ARL/SLAD

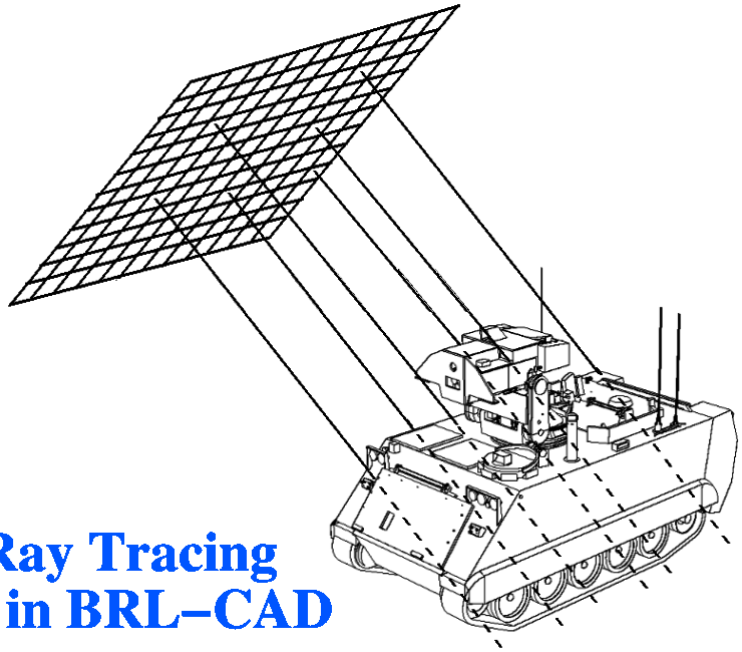
Paint-the-Night

- 8-12 micron IR image generator.
- SGI Performer based.
- Uses outboard image processor for sensor effects.
- A large highly tuned monolithic application
  - +With exceptionally high performance.
  - +Highest polygon rates seen on a real application.
- Individually drawn trees (2 perpendicular polygons)
- Individually drawn boulders.

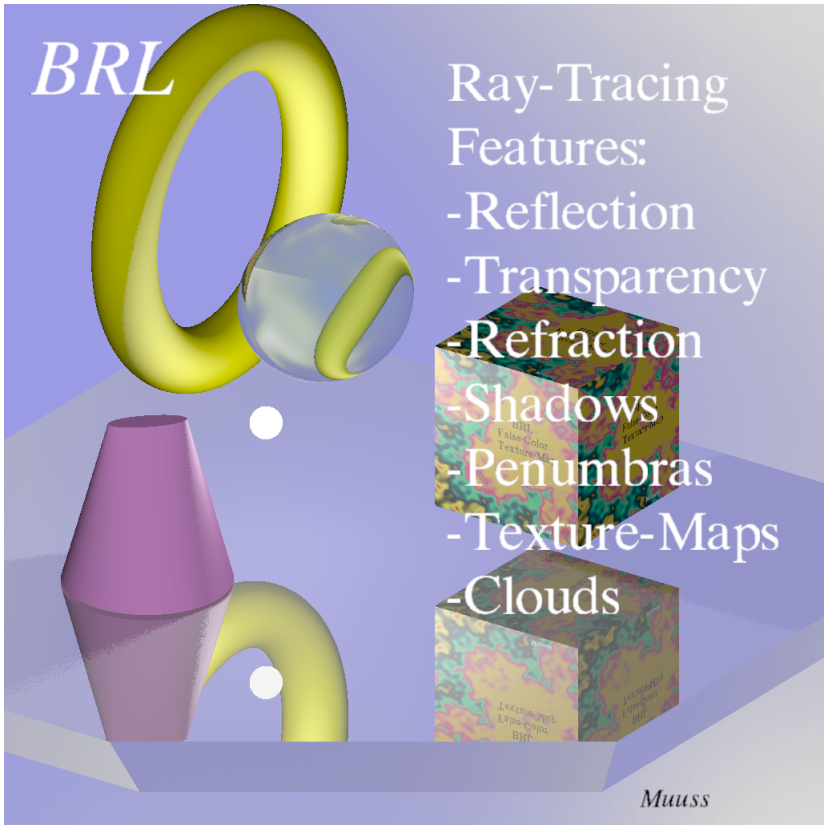
SWISS

- A physics-based synthetic wide-band imaging spectrophotometer
  - +A camera-like sensor
  - +Looks at any frequency of energy.
- A set of physics-based virtual worlds for it to look at:
  - +Atmosphere, clouds, smoke, targets, trees, vegetation, high-resolution terrain.
- A dynamic world; everything moves & changes.

Ray-Tracing Overview



Ray Tracing
in BRL–CAD



Advantages of a Ray-Tracing SIG

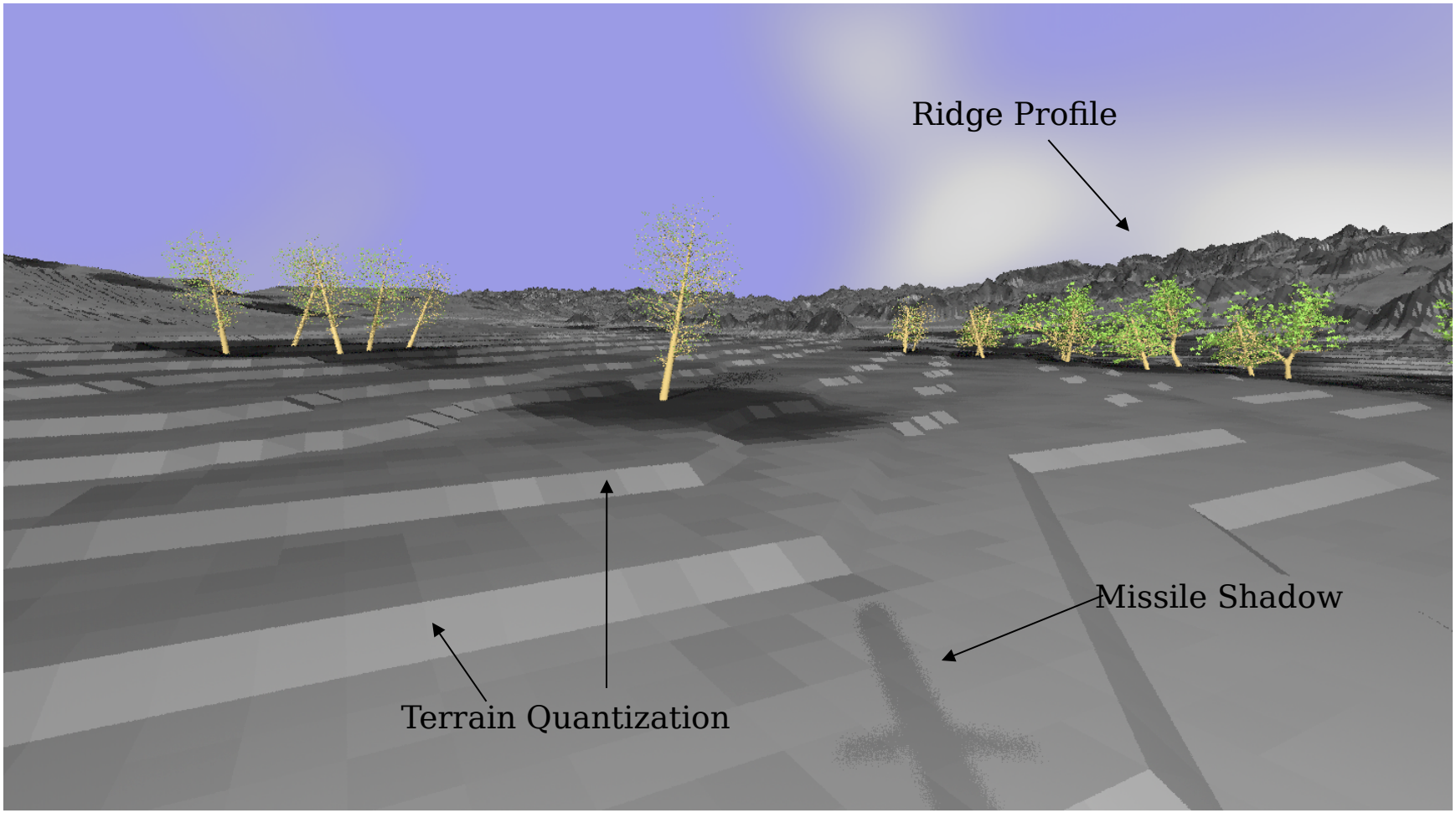
2nd-Generation FLIR image
(Downsampled to 1/4 NTSC)

- Allows reflection, refraction:
  - + Windshields, glints.
  - + Branch reflections, 3-5.
- Atmospheric attenuation, scattering.
  - + Individual path integrals.
- Accurate shadows:
  - + Haze, clouds, smoke.
- Multiple light sources:
  - + Sunlight, flare, spotlight.

CSG Rendering Advantages

- Ray-traced CSG is free from limitations of hardware polygon rendering:
  - +No approximate polygonal geometry.
    - No seams, exact curvatures.
  - +Exact profile edges. Important for ATR!
  - +No level-of-detail switching, no “popping”.
  - +Full temperature range in Kelvins, not 0-255.
  - +Unlimited spectral resolution, not just 3 channels.

Cruise Missile Shadow



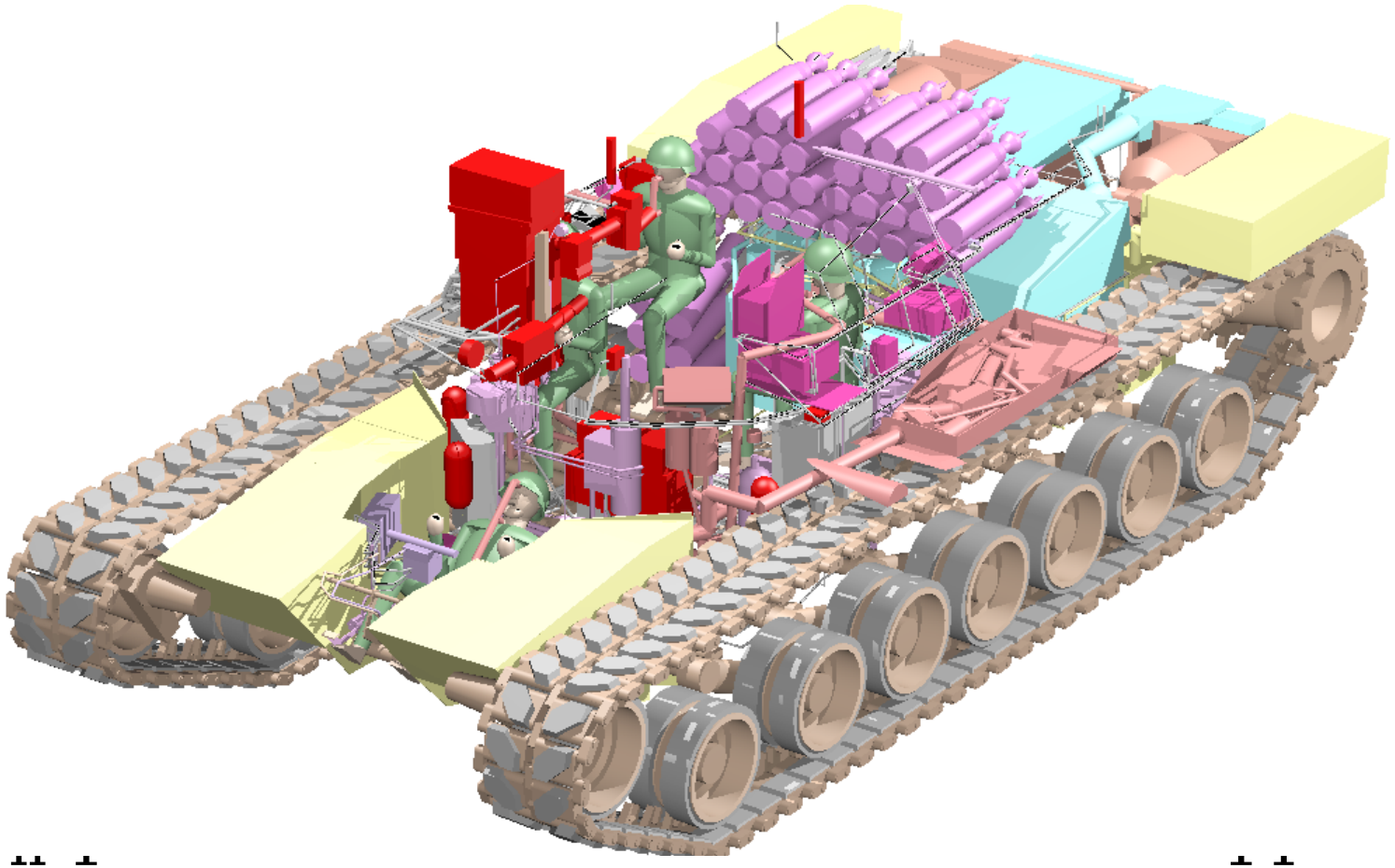
A Grand-Challenge Computing Problem

- Real targets, enormous scene complexity, > 10Km^2.
- Physics-based hyper-spectral image generation.
- Nano-atmospherics, smoke, and obscurants.
- Ray-traced image generation, exact CSG geometry.

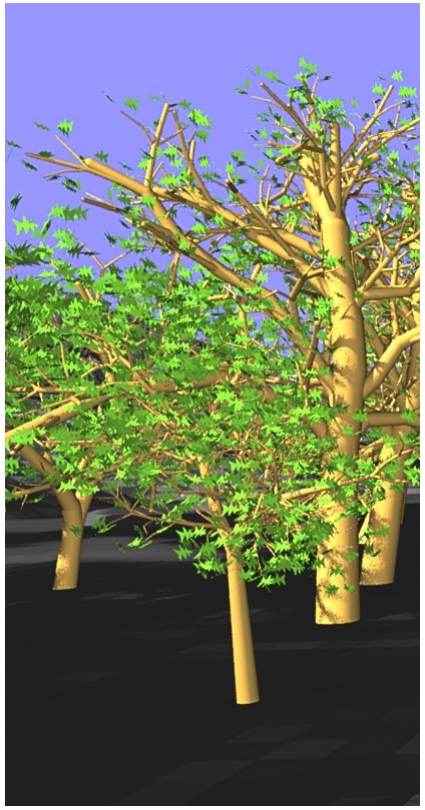
  +Near-real-time (6fps).
- Fully scalable algorithms.
- Network distributed MIMD parallel HPC.
- Image delivery to desktop via ATM networks.

Target Geometry Complexity

- Need at least 1cm resolvable features on t



Complex Geometry Today



Current

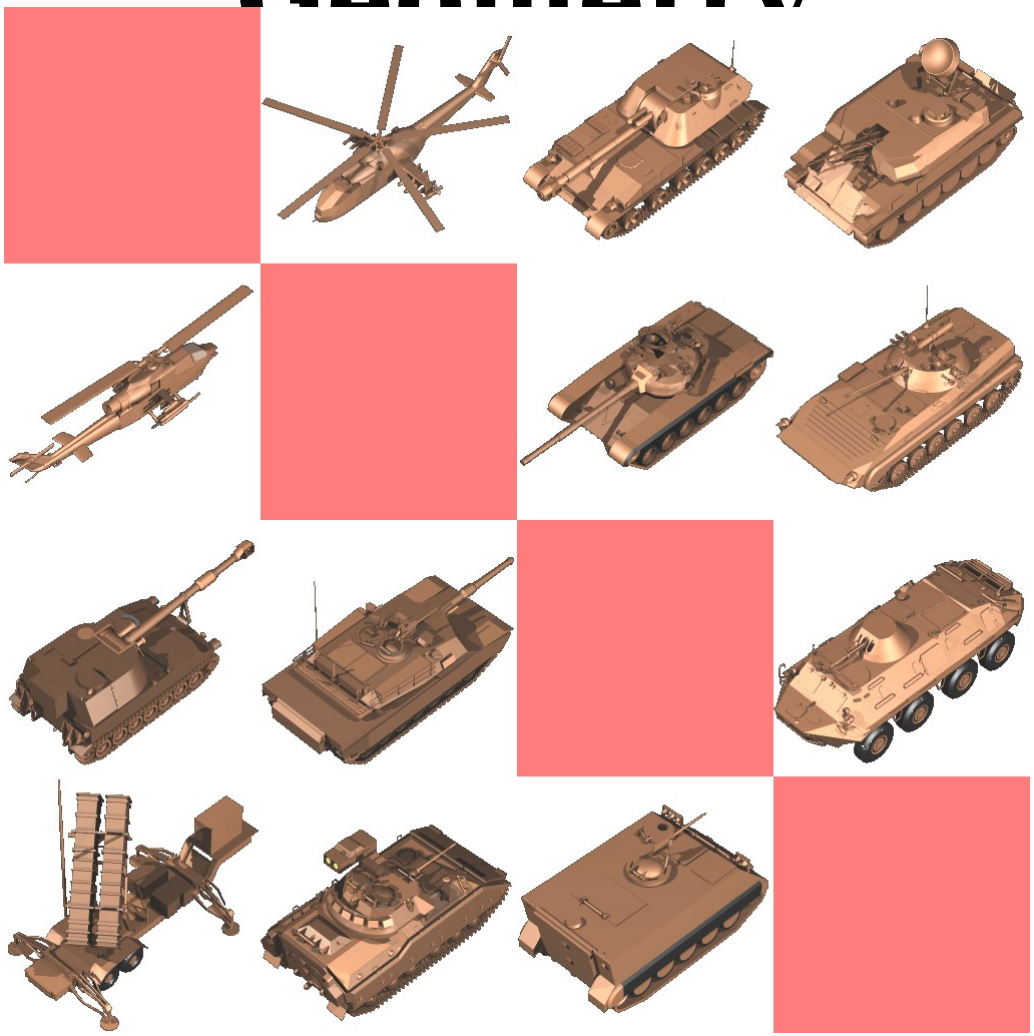
- < 1cm target features.
- 1m terrain fence-post spacing
- Three-dimensional trees:
  - +Leaves.
  - +Bark.
- Procedural grass, other ground-cover.
- Boulders, other clutter.

Developmental

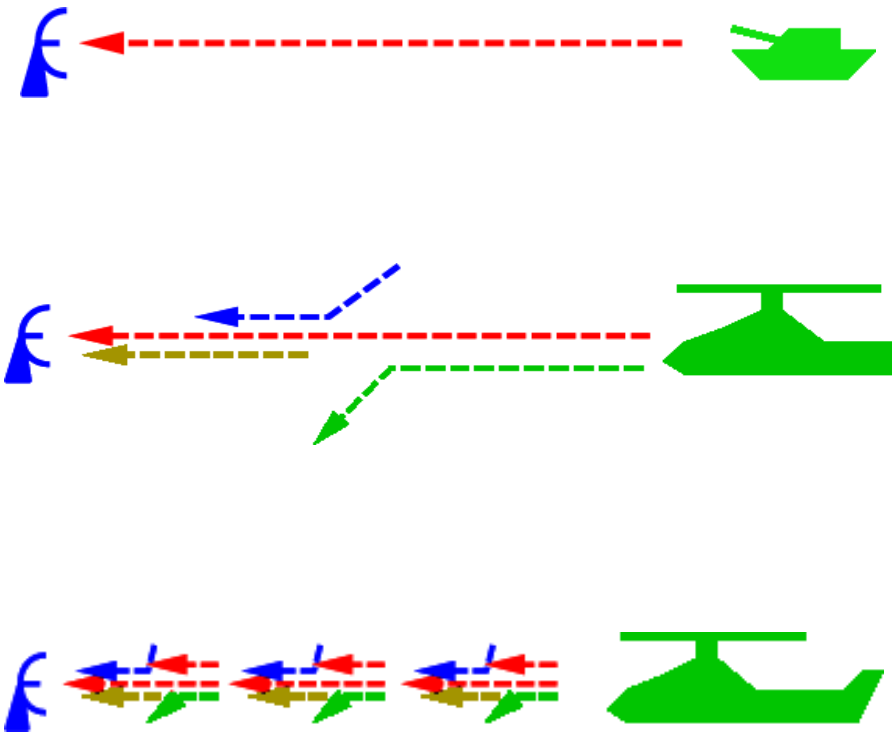
One Geometry, Multiple Uses

- To compute ballistic penetration & vulnerability:
  - +Need 3-D solid geometry and material information.
- The same targets are also useful for:
  - +Signatures: Radar, MMW, IR, X-ray, etc.
  - +Smoke & Obscurants simulation.
  - +Chem./Bio agent infiltration.
  - +Electro-Magnetic Interference.

Library of Existing BRL-CAD™ Geometry

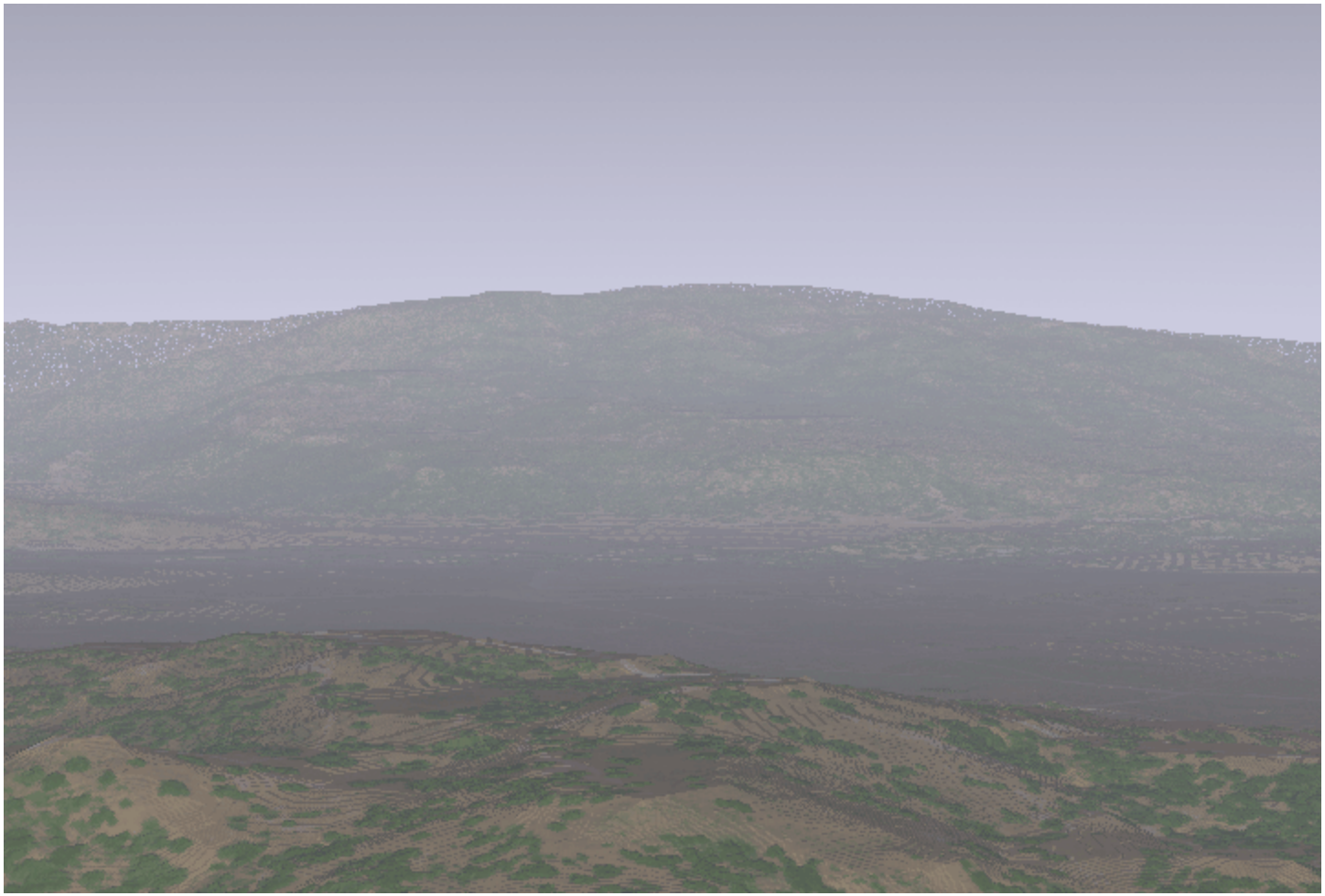


Ray-Traced Atmosphere



- Propagation easy in vacuum!
- Modeling four effects:
  - + Absorption
  - + Emission
  - + In-scatter
  - + Out-scatter
- Computer can’t do integrals.
  - + Repeated summation
  - + Discretized atmosphere

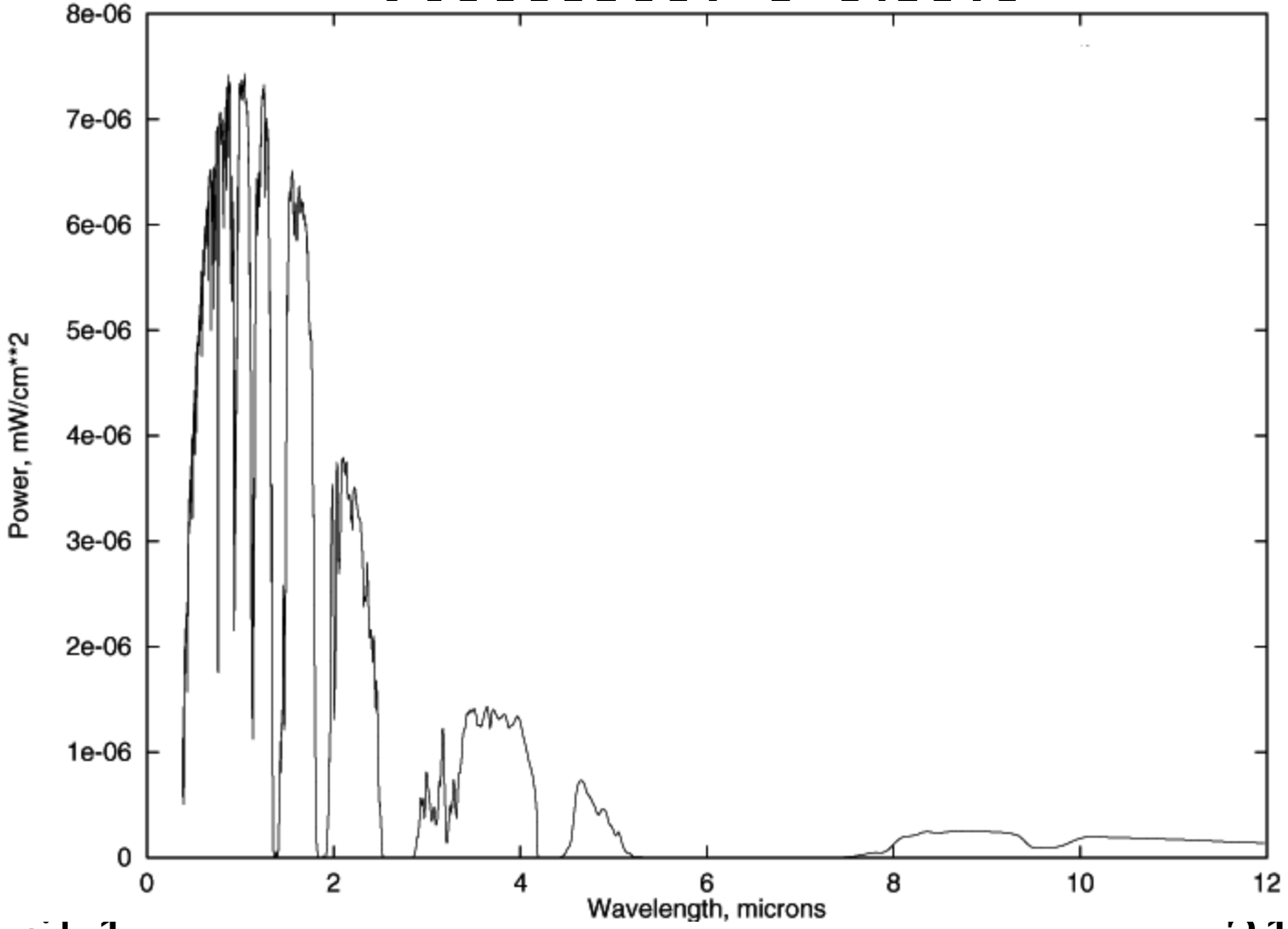
The Blue Hills of Fort Hunter-Liggett



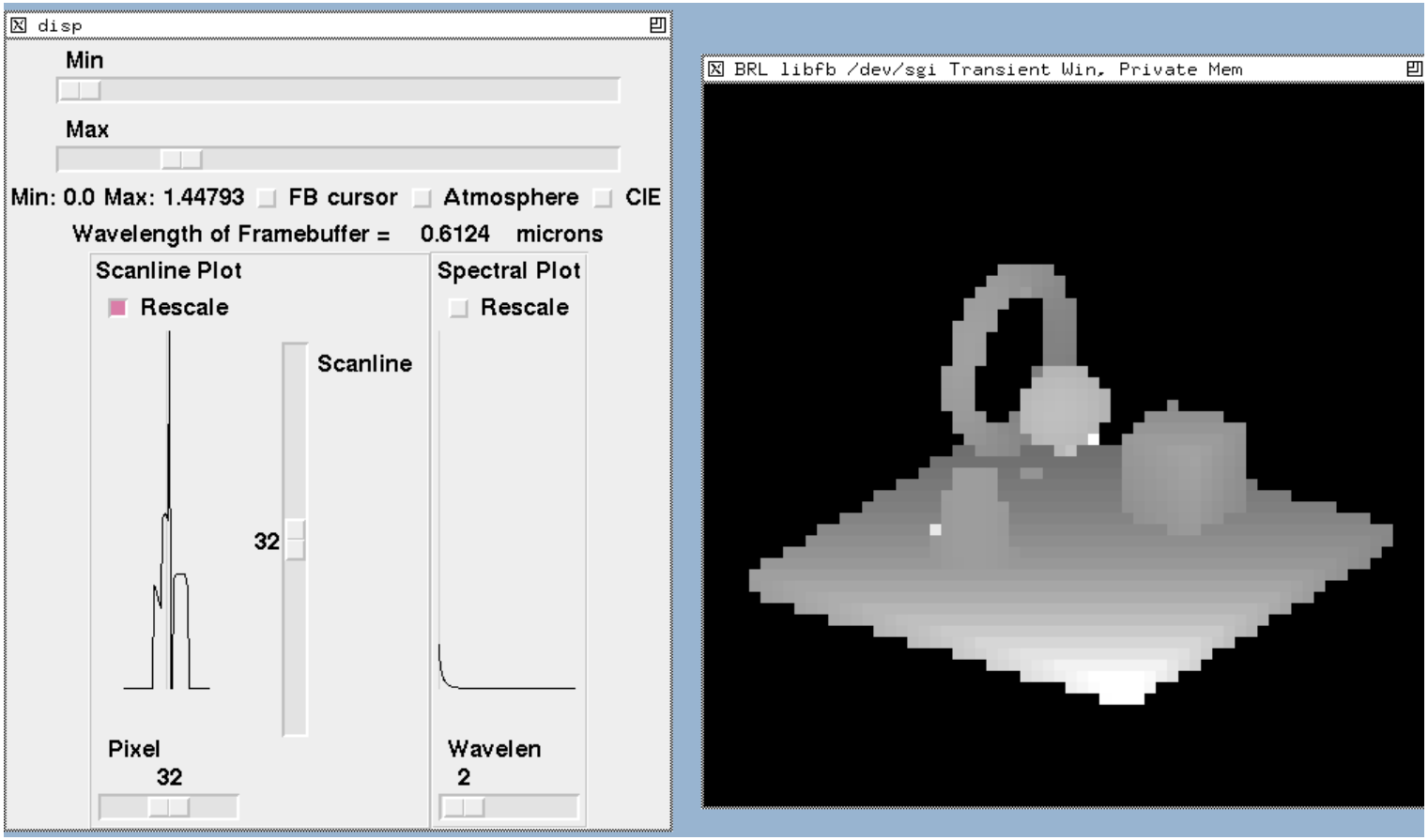
Sources of Volumetric Atmospheric Data

- Need gas-density(x,y,z) for each gas species.
- Sources:
  - +Predictive: Nano-meteorology model.
  - +Re-enactment: input from measurements.
    - E.g. Smoke-week data.
  - +Statistical: noise, FBM, fractals.
    - Generates data with specified statistics.

Hyper-Spectral: The Power of a Single Pixel



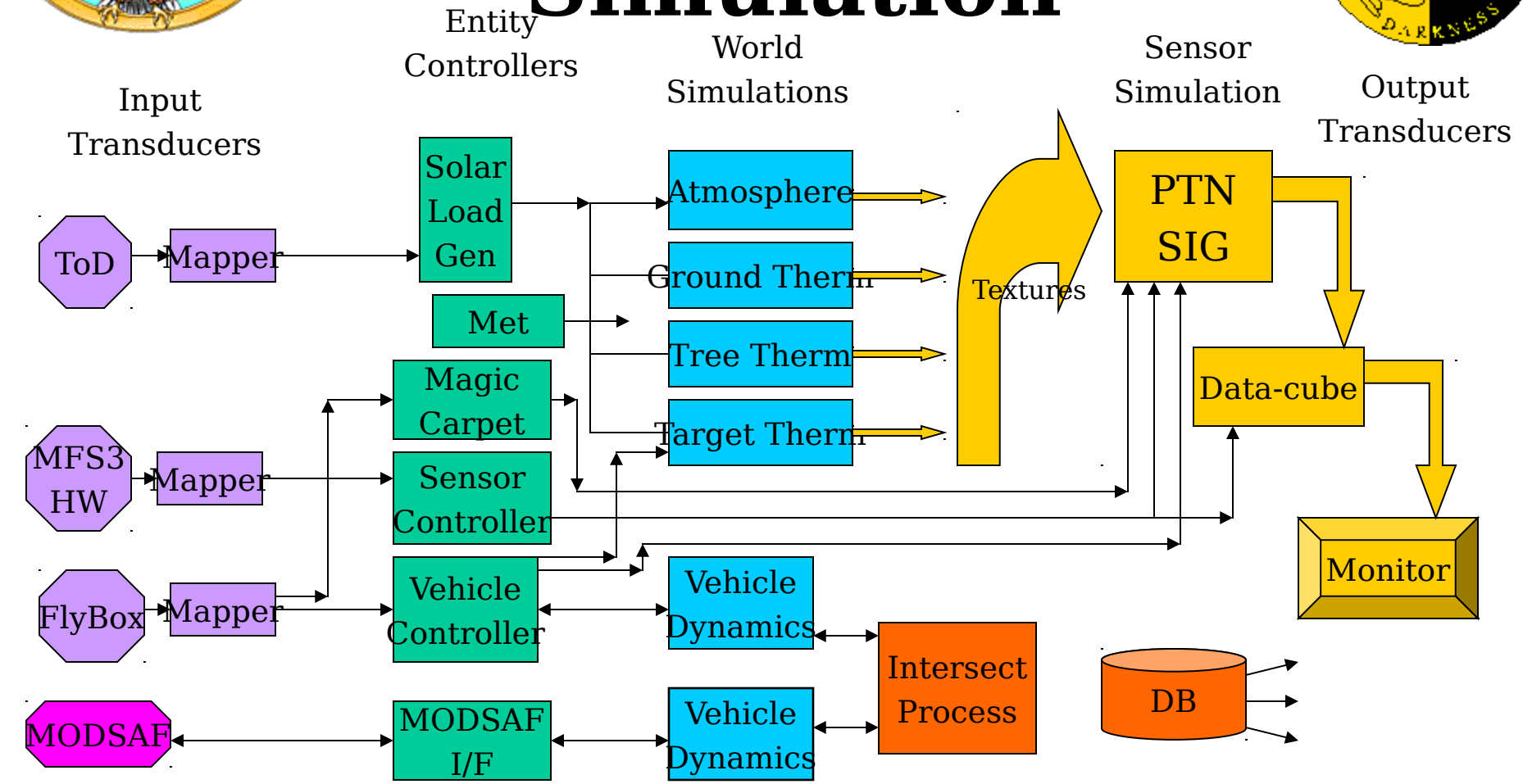
Real-time Spectral Analysis



PST Implementation Goals

- To have a software backplane:
  - +Allowing each function to run as separate process.
  - +Allowing easy reconfiguration.
  - +Allowing independent software development.
  - +Using common geometry throughout.
  - +Multiple Synthetic Image Generator (SIG) types.
    - Keep simulation details out of the SIGs.

A Basic PST Simulation



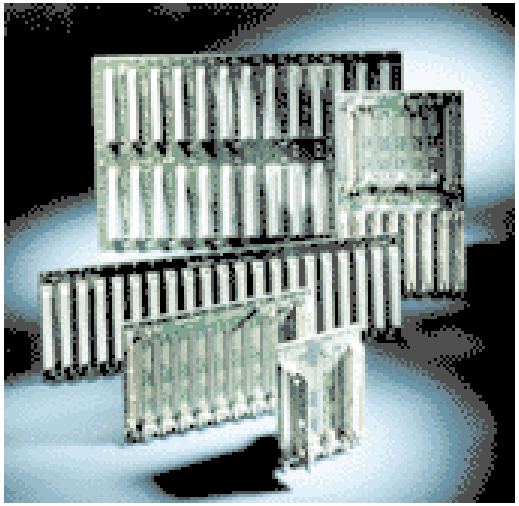
Independent Time Scales

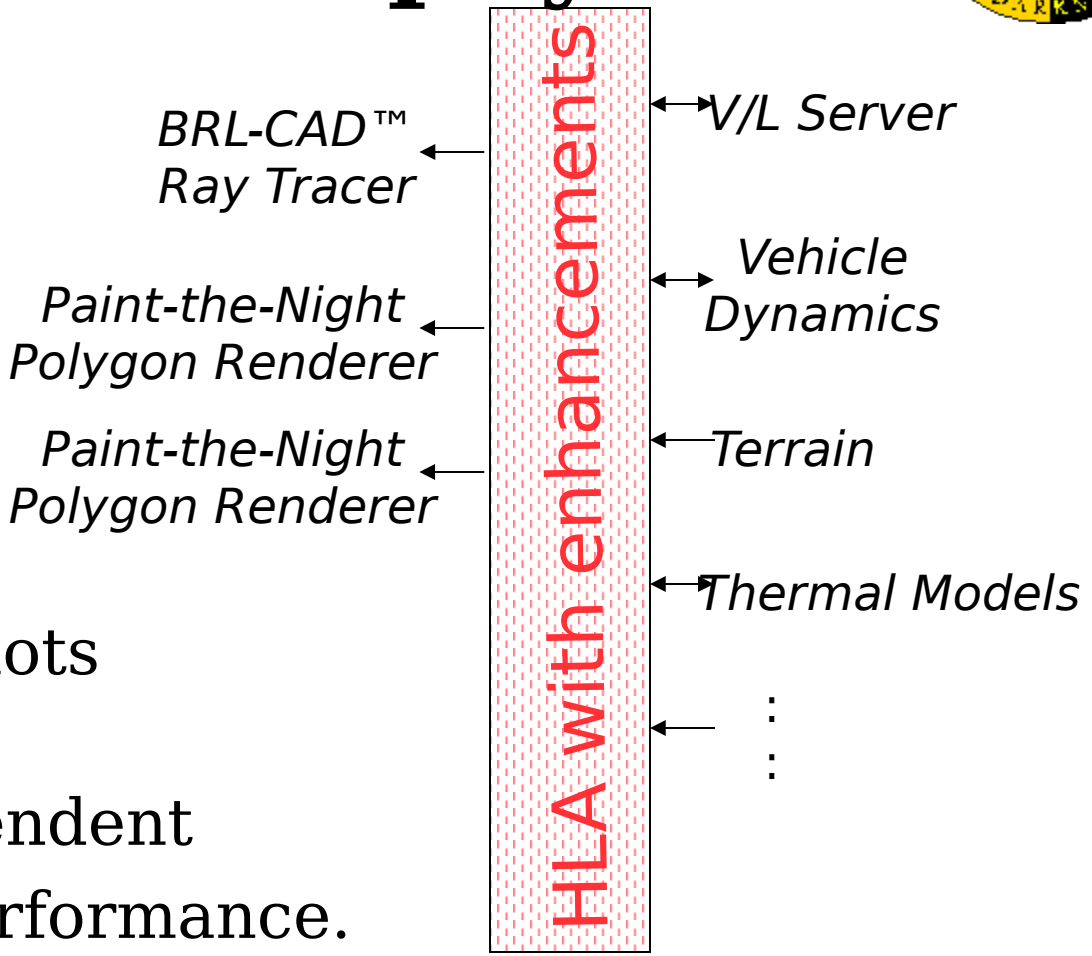
- Image generators need to run fast:
  - +30 Hz for humans.
  - +6 Hz is fastest acquisition rate of ATRs.
  - +800 Hz for non-imaging sensors (Stinger rosette).
- Physics-based simulations can run slower:
  - +90 sec/update for thermal & atmosphere models.
- Transient effects need to be added as a delta:
  - +Leaf flutter, explosions, smoke details.

Hardware Environment

- Multiple CPUs per cabinet.
- Multiple cabinets linked via OC-3 or OC-12 ATM.
  - +Geographically distributed (Belvoir, APG, Knox).
- Multi-vendor system, e.g.:
  - +Cray vector machine for thermal mesh solution.
  - +SGI Origin 2000 for parallel ray-tracing.
  - +SGI Infinite Reality for polygon rendering.
- 100-200 processors participating.

Backplane Philosophy





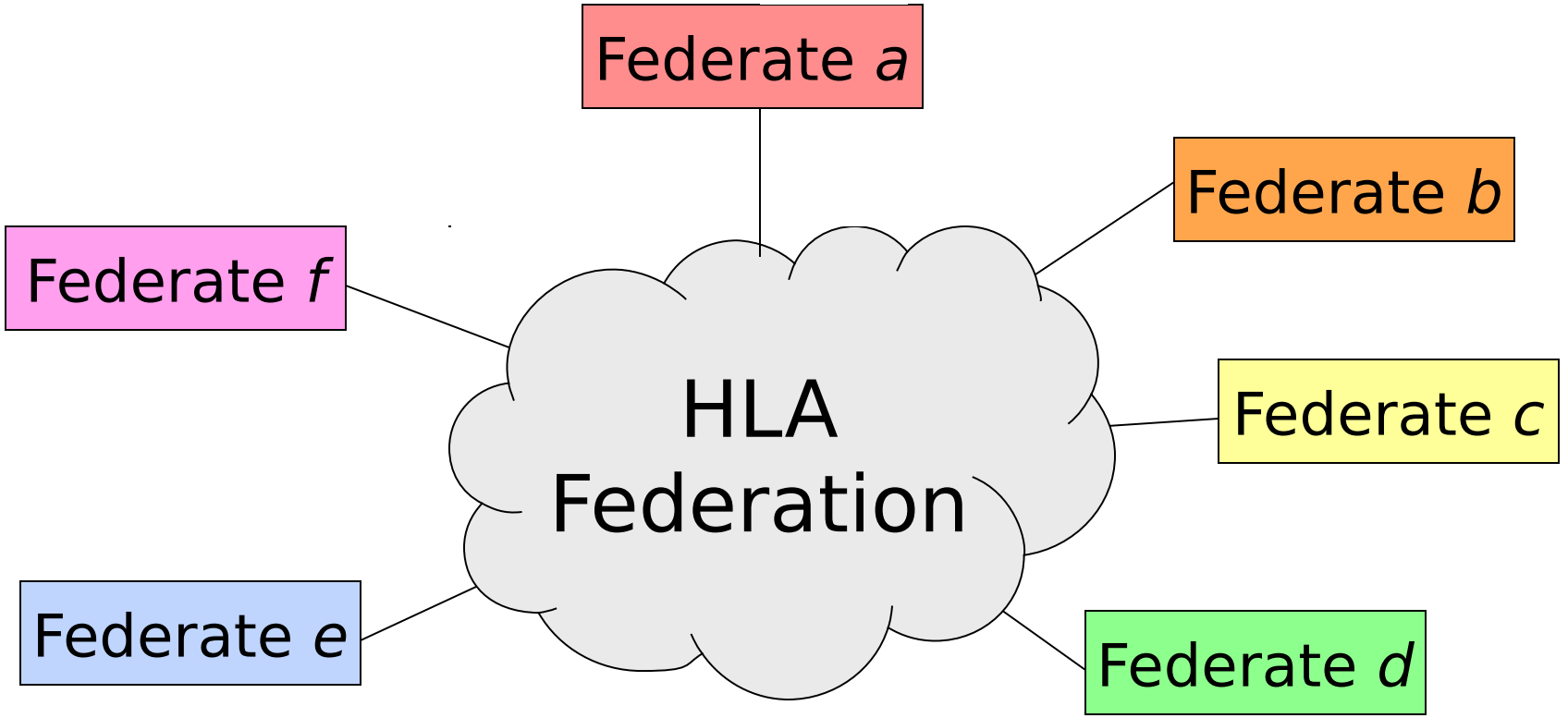
- Standardized Slots (Interface).
- Location independent
  - +Except for performance.

PST Implementation Plan

- Attempt to implement PST using HLA.
  - +Concern over real-time performance.
  - +No support for bulk data transfer.
- Fall back on JMASS, TARDEC, or home-brew.

HLA Features

Publish and ***subscribe*** to ***objects*** and ***interactions***



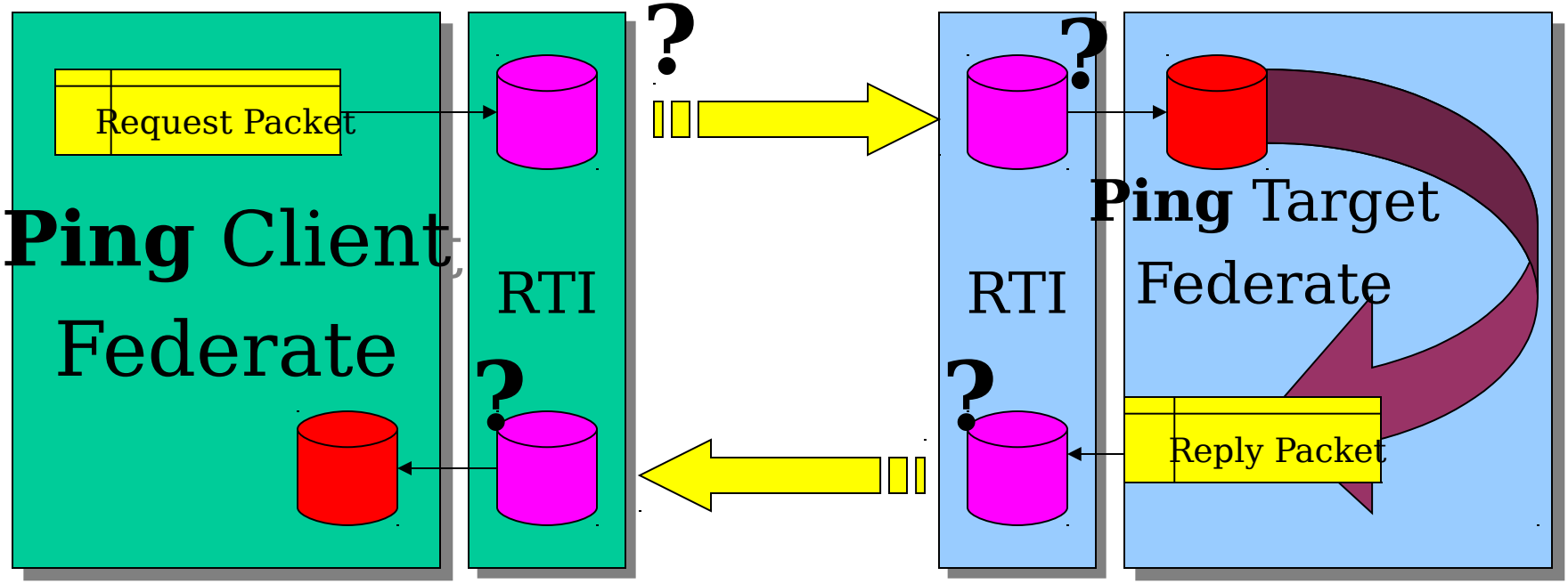
Required Backplane Features

- Event Services
  - +Implement with HLA interactions.
- Query/Response Services
  - +HLA interactions with custom routing space.
- Continuous/Bulk Data
  - +Custom Distributed Shared Memory software.
    - Auto-broadcast, optional subscriber notification.
    - Notification, subscriber polls for data update.

HLA Ping

- Tool to measure communications delay.
  - +Patterned after Muuss's TCP/IP **ping** tool.
- Special **ping** client federate.
- Common **ping** server interaction in all federates.
- Uses *federate_id* routing space for efficiency.
- Measurements:
  - +Round-trip (interaction pair).
  - +Half-trip (if both federates in same cabinet).

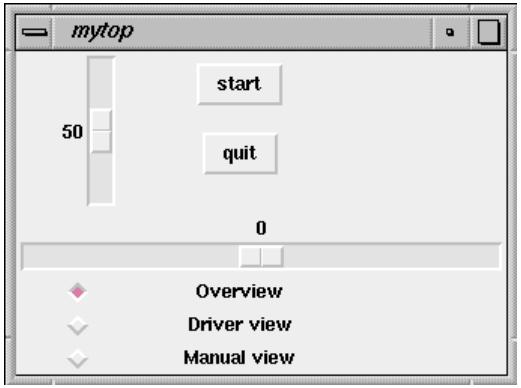
HLA Ping Diagram

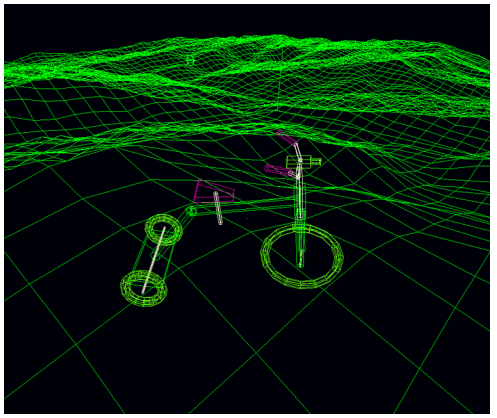


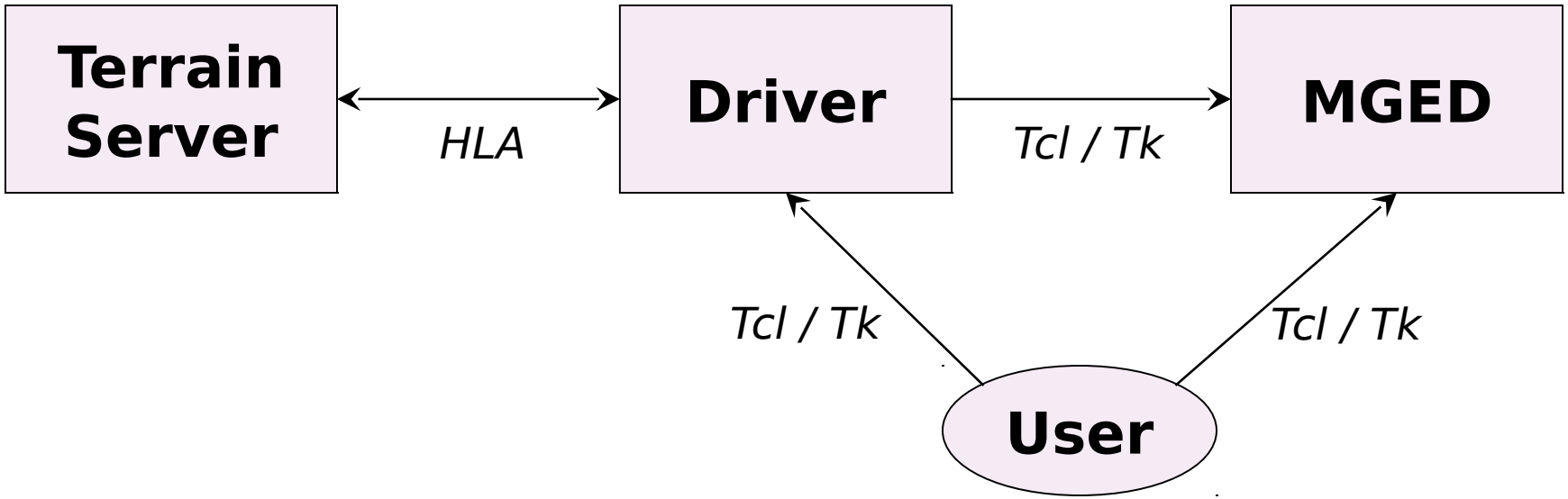
PST FOM Basics

- ECEF coordinates, 64-bit IEEE double precision.
- Using Quaternions to represent orientation.
- Entity motion always sent in motion_t:
  +Position, velocity, acceleration,
  +Orientation, Orientation dot, Orientation dot dot.
  +Facilitates dead-reckoning in SIGs, simulations.
- Point-of-View interaction: motion_t & “handle” obj.
  +Moving POV stays attached to moving entity.

VPG Demonstration







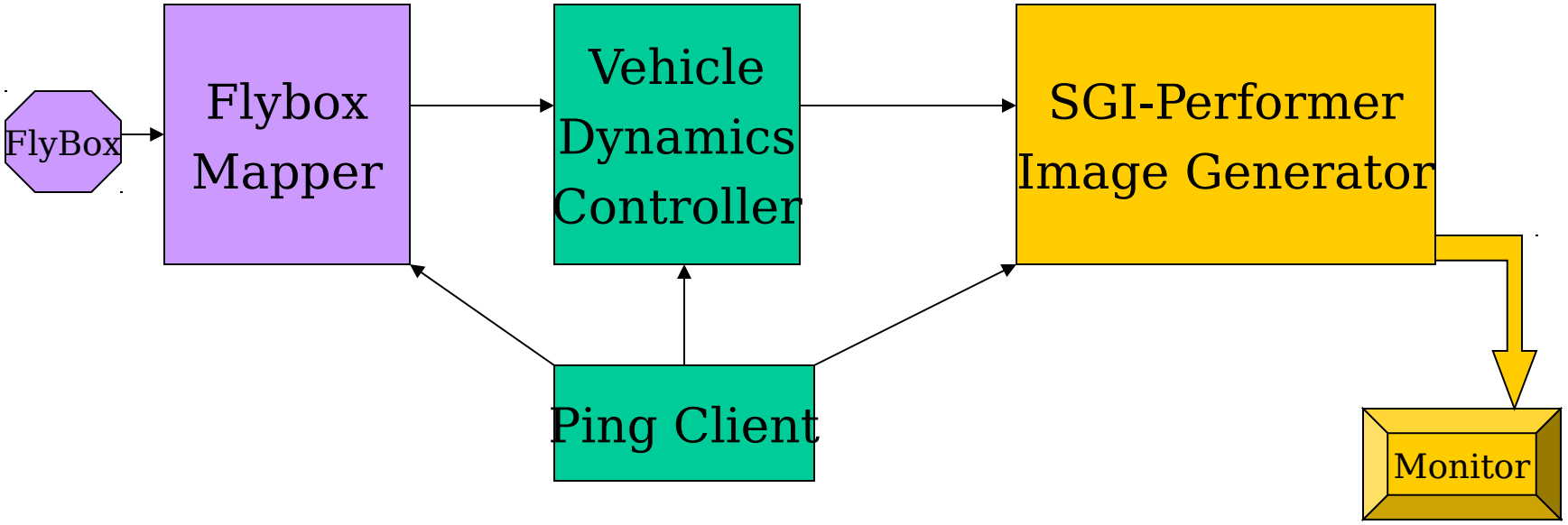
Geometry Database

- A superset collection. Each entity will have:
  - +The original BRL-CAD™ CSG model.
  - +Polygonal models at various LoD.
  - +Optical and thermal textures.
  - +Iconic representations: e.g. burning, destroyed.
  - +Nodal decomposition for input to thermal solvers.
  - +Articulation graph
  - +Definition of damage-state vector.

Two HLA Wrappers

- Muuss strategy: Hide all HLA and XDR inside C++ “send” and “receive” methods.
  - +One C++ object for each HLA interaction & object.
  - +Simulations need little HLA, C++ objects need lots.
- Baldwin strategy: Build total-insulation library.
  - +C++ objects know nothing about HLA.
  - +But XDR becomes very difficult.

Working Testbed

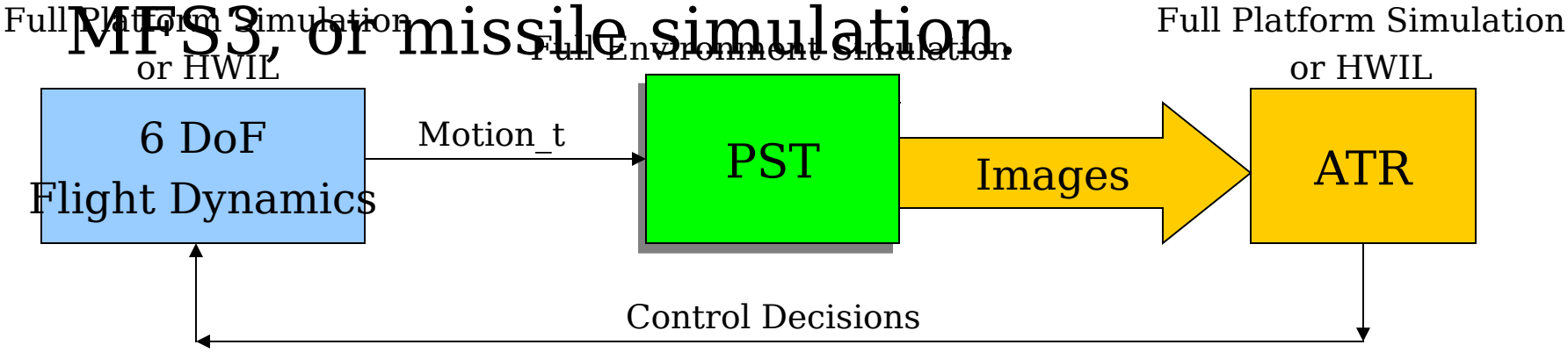


Facilitating the "GOD GUI"

- We desire the ability to reach into a running simulation and "force" parameters.
  - +E.g. teleport a vehicle, heat some ground...
- Use HLA object ownership, or one multi-cast application-layer interaction?
  - +Object ownership uses 8+ network transmissions.

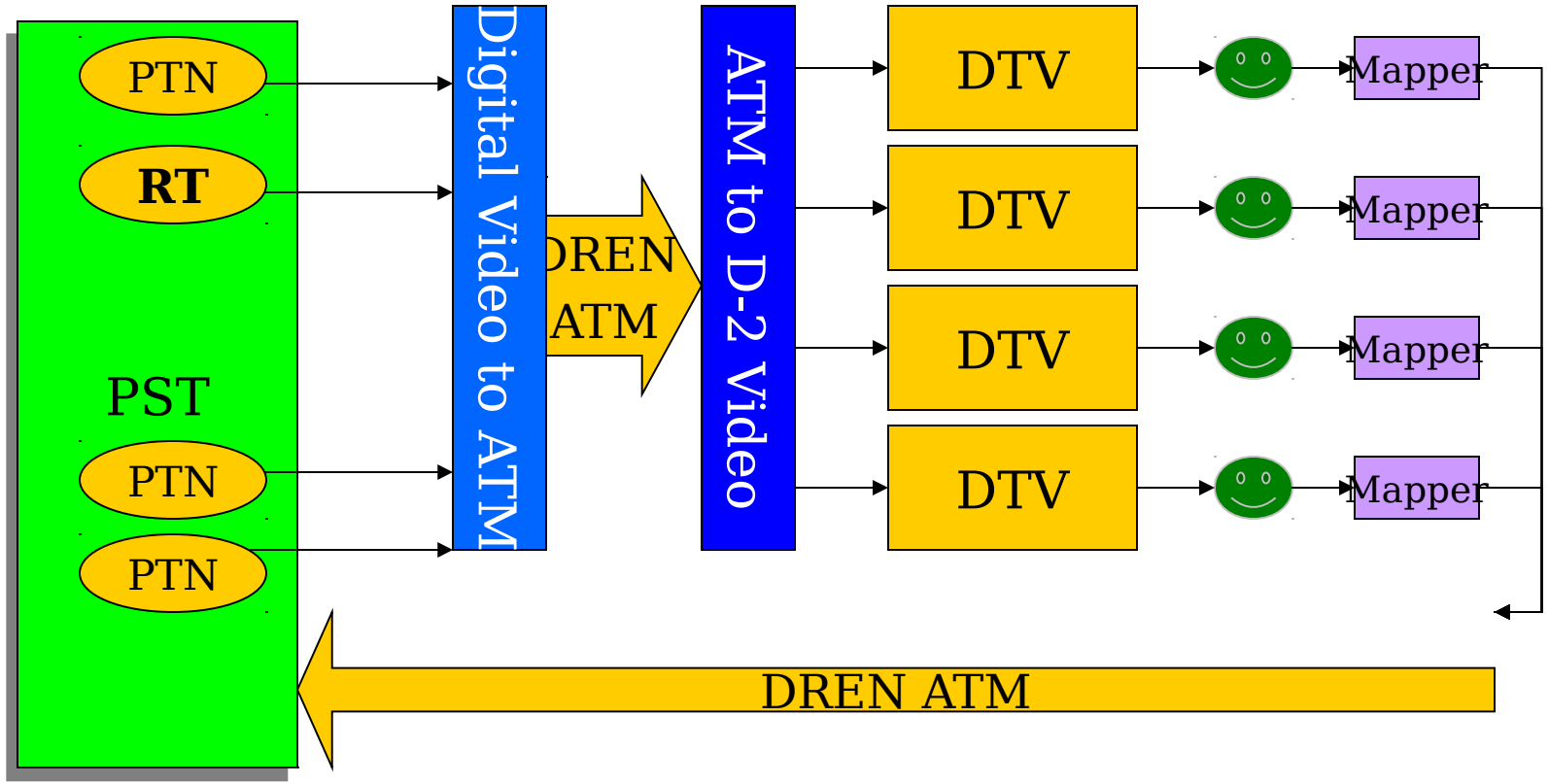
Application of PST

- The image generator is just one component of a larger simulation. E.g. MFS3, or missile simulation.



Ft. Knox Application of PST

- 1 RT SIG, 3 SGI SIGs, soldiers-in-the-loop.



Who is this MUUSS Fellow, Anyway?

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